CORN (*ZEA MAYS* L.) HYBRIDS AS AFFECTED BY ROW SPACING:
I. GRAIN YIELDS, COMPONENTS OF YIELD, AND GRAIN NITROGEN OF FIVE DOUBLE CROSS HYBRIDS.
II. TOTAL NITROGEN AND NITRATE NITROGEN IN DIFFERENT PLANT PARTS OF SIX SINGLE CROSS HYBRIDS.

by

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TABLE OF CONTENTS

Page

INTRODUCTION

Traditionally, corn (Zea mays L.) has been grown in rows spaced from 36 to 44 inches apart to accommodate planting, cultivating, and harvesting machinery. In the past the wide row spacing was necessary to facilitate horse-drawn tools. Wide row spacing for modern machinery is not needed, and harvesting machinery for 30-inch rows was made available on the market for the first time in 1963.

The yield of corn may be affected by the number of ears per plant and the ear weight. The row spacing can affect the response of a particular hybrid with respect to either of these factors.

In areas where other row crops such as soybeans or grain sorghum, which respond relatively better to narrow rows, are grown, farmers are becoming increasingly interested in narrow rows for corn. If corn planted in narrow row spacings yields as well or better than corn in conventional row spacings then farmers could realize as great or greater returns from both crops. Net profit would also be greater because machinery could be used on a larger acreage.

An experiment was performed in 1963 to determine if row spacing would have any differential effect on the grain yield and the components of yield of various corn hybrids.

In 1964 a similar experiment was initiated but because of severe weather conditions during the growing season, the objectives were altered. It was decided to determine the differences among the corn hybrids with respect to total and nitrate nitrogen and the relationship between these two classes of nitrogen.

REVIEW OF LITERATURE

Row Spacing Experiments

Hoff and Mederski (1960) found in nearly all cases the components of yield (ears per plant and weight per ear) in 42-inch rows were adversely affected as the population increased over an equidistant spacing pattern. As the population increased from 8,000 to 24,000 plants per acre, the yield of both the 42-inch rows and equidistant pattern also increased; however, the yield of the equidistant spacing was consistently higher than the 42-inch row spacing. Ears per plant were lower for the 42-inch row spacing and as the population increased, the ears per plant decreased faster in the 42-inch row spacing than the equidistant spacing.

Ear weight of the equidistant spacing was about 0.1 pound less than the 42-inch rows and both decreased linearly with increased population. Thus, the reduced yield was attributed to the reduced number of ears per plant.

When looking at the spacing patterns of this experiment, there were 42-inch rows compared to 28-, 23-, 20-, 18-, and 16-inch row spacings at five populations. As the row width decreased and the population increased, the yield was increased.

Yao and Shaw (1963) found as the row width was decreased from 42 inches to 32 inches to 21 inches, yield increased. Their experiment was conducted using two populations. One experiment had single plant hills and the other had two plants per hill. The highest average yield was recorded at the high population in 21-inch rows. They also found the 21-inch rows to produce more grain per acre-inch of water used than any other row spacing.

Using a brachytic 2 dwarf hybrid, Pendleton and Seif (1961) found 30-inch rows to outyield both 20-inch and 40-inch rows by about 5 percent. Most of the variation in yield was attributed to ear weight. Maximum yield was attained at 30-inch row spacing at 16,000 to 20,000 plant population. The dwarf corn performed similarly to normal corn. The narrow rows required an increased population for maximum yields.

Experimental attempts to evaluate the effects of row spacing in corn have produced erratic results. Some have shown no differences of one spacing pattern over another (Bryan et al., 1940; Stickler and Laude, 1960). Others have shown from a 5 percent yield advantage for narrow rows (Pendleton and Seif, 1961) to as much as 38 percent advantage (Coville and Burnside, 1963). Pfister (1942) noted a 27-bushel per acre advantage for 20- x 20-inch spacing over 40- x 40-inch spacing.

Brown and Shrader (1959) studied the effects of soil moisture levels on row width and population levels of grain sorghum, and found yield differences due to row width and population were significant at the one percent level of probability at the two highest levels of moisture in two years of the experiment.

In 1954, 20-inch row spacings had the highest yield followed by the 10-inch spacing; the 40-inch spacing had the lowest. In 1955, yields were very low and erratic because of drought. The water use efficiency was highest in 1954 in the 20-inch rows followed by the 40-inch rows; the 10-inch rows were lowest.

Under irrigation in Texas (three-year average yield), significantly higher yields of grain sorghum were obtained in 12- and 20-inch row spacings than in 30- and 40-inch row spacings (Porter et al., 1960). A more uniform distribution of plants over the cropped area apparently resulted in more efficient use of moisture, nutrients, and solar energy, and, consequently, in higher yields at the narrower row spacings. The 20-inch rows had the highest average water use efficiency.

In Colorado, grain sorghum in 20-inch spacing exceeded 40-inch spacing only at highest moisture levels (Bond et al., 1964). Lodging was reduced in the 20-inch rows by as much as half that recorded in the 40-inch rows.

Averaging three populations at 10-, 20-, 30-, and 40-inch row spacings, Robinson et al., (1964), found highly significant yield increases as the row width decreased from 40 inches. This was a two-year average at three locations in Minnesota. Population had no significant effect on final grain yield. More plants grew to maturity in the 10-inch spacing than in the wider spacings. This increased the panicles per acre. Panicle weight increased with decreased row width as did the seed per panicle. The moisture percentage also increased with decreased row width.

In Minnesota, soybeans in 40-inch rows were compared to 20-inch rows at two locations at within row spacings of 3, 1.5, 0.75, and 0.5 inches (Lehman and Lambert, 1960). Twenty-inch rows produced nine percent higher yields than the 40-inch rows. As the population increased in the 20-inch rows, the yields dropped; the reverse held true for the 40-inch rows. It should be remembered, however, the population in the 20-inch rows was actually double that in the 40-inch rows.

There was little difference in the number of seeds per pod. On a per plant basis the difference was due to the number of pods produced per plant. The 40-inch rows produced nearly 57 percent more pods per plant than did the 20-inch rows. The 57 percent more pods per plant was insufficient to offset the greater number of plants in the 20-inch rows.

In Kansas, Mader (1963) found soybeans in 20-inch rows to yield more than 30-inch rows which yielded more than 40-inch rows at two locations.

Hildebrand _et al_. (1959) report yield increases as much as 20 percent in rows spaced 18 inches apart over 40-inch spacings. This trend seems to hold true for all northern areas of the United States but not always in the southern areas. The advantages of narrow rows increase in all states in late plantings (Johnson _et al_., 1959).

Mader _et al_. (1963) list four reasons for planting soybeans in narrow rows:

"1. Seed pods farther from the ground.
2. A vegetative canopy that suppresses weeds earlier.
3. Easier combining when lodged in narrow rows than in wider rows.
4. Particularly better yields when late planting is necessary."

Burlison _et al_. (1940) found soybeans to yield more when drilled in 24-inch rows than when "drilled solid" with an 8-inch grain drill. This was a five-year average of one variety.

In Indiana, best yields were obtained at plant spacings of 1.5 to 3.5 inches in 28- to 40-inch rows (Beeson and Probst, 1961). Soybeans planted one to four or five inches within row spacings show little variation in yield (Probst, 1945; Lehman and Lambert, 1960). Experiments with soybeans involving row width often confound the population. The per acre population is inversely proportional to the row width.

Nitrates in Plants

Nitrate as a toxic agent in forages was first described by Mayo (1895). He examined corn fodder and corn stalks believed to be the cause of deaths of cattle and found crystals of potassium nitrate at the cut surfaces, in the leaf axials, and in the pith tissue of the stalk.

The samples proved to contain as much as 3.5 percent nitrate nitrogen.[1] On the basis of this analysis and an earlier observation, Mayo fed potassium nitrate to three calves, all of which died.

The action of the toxic agent remained unknown until Rimington and Quin (1933) recognized the significance of the abnormal brown colored blood of animals poisoned. Spectroscopic examination of the blood of the dead animals revealed as much as 80 percent methemoglobin. They concluded that nitrate was reduced to nitrite in the animal's rumen by the microflora present. The nitrite then was absorbed by the circulatory system of the ruminant causing the formation of methemoglobin and resulting in the death of the animal by asphyxiation or methemoglobinemia in cases which survived.

The first American workers to make progress beyond Mayo's work were Bradley _et al_. (1940a), who are usually credited with the discovery of nitrate induced methemoglobinemia. They concluded that 77 milligrans NO_3-N per kilogram body weight was the minimum lethal dose for cattle. Toxic level in forages was arbitrarily set by them at 0.21 percent nitrate nitrogen (1.50 percent KNO_3). They found horses to be susceptible, though

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[1] A majority of the 36 research workers and industrial representatives attending a Conference on Nitrate Accumulation and Toxicity held in New York City on April 15-16, 1963, favored standardization of reporting as follows: per cent NO_3-N, for feeds and tissues; millimoles per milliliter, for physiological solutions. This usage is followed in this paper.

possibly not so much as cattle, to nitrate poisoning. The large caecum of the horse provides for the action of microflora in the reduction of nitrate to nitrite. Seldom are other monogastric animals affected by the ingestion of nitrates. Nearly all animals are subject to toxicity by the ingestion of nitrites.

Bradley et al. (1940b) proposed a method of treatment. They found a four percent solution of methylene blue desolved in water and administered intravenously at a rate of two grams per 500 pounds of animal weight would relieve the methemoglobinemia of affected animals. This method is currently employed with only slight modifications suggested (Wright and Davison, 1964).

Most nitrogen absorbed by plants is in the nitrate form. Each atom of nitrogen that is absorbed as nitrate must undergo an 8-electron change in valence from +5 to -3 if it is to be assimulated as protein. Any accumulation of nitrate would indicate that absorption is more rapid than assimilation. The level of accumulation and factors contributing to abnormally high levels of accumulations are of primary interest here.

Rimington and Quin (1933) noted that differences in nitrate accumulation existed between different plant genera and species. Using 12 oat varieties Gul and Kolp (1960) found significant differences in the amount of nitrate nitrogen accumulated. At two locations the 12 varieties ranked in the same general order, although the levels of one location were nearly twice that of the other. They reported the highest levels at 25 percent flower with a gradual decline to maturity. There was no relationship between nitrate level and forage yield or plant height. Similarly Crawford et al. (1961) found a decline in nitrate level with maturity of the plants. This was true where the soil nitrogen was depleted as the season progressed. By maintaining a high nitrogen level in the soil the nitrate level of the plants remained high throughout the season. Varietal differences, though significant, varied only by 0.07 percent nitrate nitrogen. Shading had the greatest effect on nitrate. Shading in the early part of the growing season and continuous shading increased nitrate levels to potentially toxic levels. Applications of 150 to 200 pounds of nitrogen per acre were required to stimulate potentially toxic levels of nitrate.

Wright et al. (1960) also found extremely high rates of nitrogen fertilizer (500 to 875 pounds per acre) were required to produce toxic nitrate levels in blue panicgrass. Phosphorus-potassium and nitrogen-phosphorus-potassium interactions had no effect. Limiting the available water and the additions of large amounts of nitrogen fertilizer were the primary factors stimulating nitrate accumulation.

A curve for total nitrogen accumulation in corn follows the dry matter accumulation curve but precedes it by about 3 weeks (Sayre, 1948). Maximum accumulation of nitrogen occurred about 2 weeks after pollen shed and fertilization and remained at a constant level. Jordan et al. (1950) found the highest level of nitrogen in the plant parts at tasseling. Total accumulation (per acre) continued to increase with the development of the grain.

Jones and Huston (1914) found nitrogen and potassium were absorbed at a very rapid rate early in the life of the corn plant. Nitrogen continued to be absorbed until the plant was killed by frost. The nitrogen content of the stems decreased during the formation and development of the ear, nitrogen being assimilated faster than absorbed, then again increased as the ear matured.

Hay et al. (1953) sampled corn and noted nitrate nitrogen was low in the leaves at pollination. This level increased as the grain began to develop, then decreased after maturity. They found no nitrate in the grain. The lower stalk was initially high in nitrate and decreased during grain development. There was enough nitrogen in the plant at pollination to supply the maturing grain. After grain maturity the nitrate level again returned to a high level. They concluded nitrates were stored in the culm until needed by the plant. Nitrates were then translocated to the leaves where complex organic nitrogen compounds were assimilated and translocated to the developing fruit.

Benne et al. (1964) have presented the most comprehensive and up-to-date study of the corn plant and the mineral distribution in the various parts at different stages of growth since the introduction of hybrid corn. Toxic levels of nitrate nitrogen were reported and maintained throughout the season only in the lower portion of the culms. At no time was nitrate found in any reproductive parts or ear shanks and husks. Accumulations of mineral elements for the season were based on the October sampling date.

Zieserl and Hageman (1962) found the grain protein to be higher in corn lines having a high nitrate reductase activity. Zieserl et al. (1963) using four corn hybrids at varying populations noted no yield differences between the hybrids. Yields decreased as population increased. Specific nitrate reductase activity also decreased with an increase in population. The specific nitrate reductase activity was inversely correlated with the nitrate level. The hybrids, when ranked in decreasing order of nitrate reductase activity, agreed with the ranking of the established agronomic yield performance tests.

Similar work by Hageman et al. (1963) on the genetics of nitrate reductase activity showed a high degree of heritability. Hybrids were usually intermediate in enzyme activity between the parental lines and paralleled the lower. There were insufficient data to conclude the existence of heterosis for specific nitrate reductase activity.

Evaluating the effects of fertilization on the chemical composition of bromegrass, Hanway and Moldenhauer (1965) found that additions of nitrogen fertilizer increased both total nitrogen and nitrate nitrogen. Phosphorus applications tended to increase total nitrogen and nitrate nitrogen where soil nitrogen was adequate but where nitrogen was deficient, phosphorus had a depressing effect on nitrogen.

Under conditions of drought the complete culm of corn had levels of nitrate above that which is considered toxic (Hanway and Englehorn, 1958). This was also true of soybeans and sorghum at a mid-summer sampling date. The lower culms maintained a high level through early September. Irrigation prior to planting corn maintained safe levels of nitrate and doubled the yield. Providing adequate moisture throughout the growing season depressed the nitrate nitrogen level to 0.13 percent air dry material, while more than tripling yields.

Nitrates did not accumulate below a given level of total nitrogen in corn (Hanway, 1962). Leaves having less than 2.6 percent total nitrogen, sheaths with less than 0.7 percent total nitrogen, and stalks with less than 0.3 percent total nitrogen all contained less than 0.03 percent nitrate nitrogen. Beyond these levels of total nitrogen, nitrate nitrogen accumulated with a linear relationship between the two forms of nitrogen. Hanway suggested the use of nitrate nitrogen determinations of the leaves of young corn plants as an estimate of the nitrogen status of the plant.

EXPERIMENTAL PROCEDURE

1963 Experiment

Five double-cross corn hybrids were planted May 23, 1963, at the Kansas State Agronomy Farm (Manhattan). The soil was a well drained, moderately dark colored, alluvial silt loam bottom land. The subsoil color and texture were variable.

The field was fall plowed and 194 pounds of ammonium nitrate (65 pounds actual N) per acre was broadcast and disked in prior to planting.

The five hybrids used in the experiment were: U.S.-523-W [(K55 x K64)(Ky27 x Ky29)] a full season white hybrid, A.E.S.-904-W [(K64 x Mo22)(T111 x T115)] a full season white hybrid, K-1859 [(WF9 x N6)(K145 x K150)] a mid-season yellow hybrid, N-504 [(WF9 x Hy2)(N6 x M14)] an early yellow hybrid, and Crow's M-39, a closed pedigree mid-season yellow hybrid.

The plots were planted double (in row spacings of 20, 30, and 40 inches) and when the plants were 6 to 10 inches tall were thinned to 13,500 plants per acre. The experimental design was a randomized complete block replicated four times with row spacings as sub-plots and hybrids as whole plots. Weed control was attained by a broadcast application of 4.0 pounds per acre (active material) of Atrazine after planting.

The plot length was 20 feet. Four 40-inch, five 30-inch, and eight 20-inch rows constituted the sub-plots. Yield data were taken from the center 2 rows of the 40-inch plots, the center 3 rows of the 30-inch plots, and the center 4 rows of the 20-inch plots. Yields were adjusted for the various row spacings. Stand and ear counts were made at harvest. All grain yield data were corrected to 15.5 percent moisture. Nitrogen content of the grain was determined by the boric acid modification of the Gunning-Kjeldahl method (Association of Official Agricultural Chemists, 1955) and expressed as percent of dry weight. Snedecor (1962) was used as the authority for all statistical analyses.

1964 Experiment

The 1964 experiment was originally designed to evaluate the effect of row spacing on the yield of corn hybrids, similar to the 1963 experiment. Because of a hail storm that occurred on July 3, 1964, and the severe drought following the hail storm, no yields were obtained.

Six single-cross hybrids involving four inbred lines in all possible combinations, but not including reciprocal crosses, were utilized throughout the 1964 experiment. The inbred lines were WF9, 38-11, C-103, and Hy2.

The design was a randomized complete block with row widths as sub-plots and hybrids as whole-plots. Row spacings were 20 and 40 inches. Two plants were planted per hill and later thinned to one plant per hill. Plants were left in adjacent hills to correct for missing hills. The sub-plot for 20-inch spacing consisted of eight rows and the 40-inch spacing had four rows 20 feet long.

Ten plants harvested from each plot constituted the whole plant sample. These were dried, the dry weight recorded, and the plants chopped. The forage yield was based on the dry weight of these ten plants. An additional five plants were taken from each plot and separated into four arbitrary plant parts. The <u>lower culm</u> samples consisted of the three lower internodes, the upper culm consisted of all the stem tissue above the ear node, the leaf sheath and leaf blade samples consisted of all the sheaths and blades, respectively.

A sub-sample was taken from the whole plant chopped material and dried for one week at 65 to 70° C. The plant-part samples were chopped and the whole sample was dried for one week. After drying, the samples were all ground in a Christy-Norris mill.

Total nitrogen was determined on all samples by the salicylic-sodium thiosulfate modification of the Gunning-Kjeldahl method (Assoc. Off. Agri. Chem., 1955). The nitrate content was determined by the magnesium oxide-Devarda alloy method (Bremner and Kenney, 1965). The method consisted of leaching 0.5 g. of plant material with 100 ml. boiling water and allowing it to cool to room temperature. A 10 ml. aliquot was pipetted into a 100 ml. micro-Kjeldahl flask and made basic with approximately 0.4 g. magnesium oxide (heavy powder). The mixture was steam distilled for 3 minutes to remove any free ammonia nitrogen from the sample. Devarda alloy (0.4 g.) was added and the sample was distilled for 4 minutes. The distillate was caught in a 2 percent boric acid solution with bromocresol green and methyl red used as indicator. The distillate was then titrated with 0.005 N sulfuric acid. All values were expressed as a percent nitrate nitrogen of dry plant material.

Statistical analyses were determined as outlined by Snedecor (1956), and Duncan (1955). General combining ability (GCA) and specific combining ability (SCA) analyses were made according to the method presented by Sprague and Tatum (1942) and Griffing (1957). The term GCA is used to designate the average performance of an inbred line in hybrid combination.

SCA is used to designate those cases in which certain combinations do relatively better or worse than would be expected on the basis of the average performance of the lines involved. These analyses were made to more clearly explain the response of each hybrid.

Nonirrigated Location

The plots were planted double on May 27, 1964, and later thinned to a final stand of 10,890 plants per acre on a well drained, unnamed alluvial silt loam bottom land. The slope was less than 2 percent with an A horizon extending beyond a depth of 12 inches. The plots were fertilized with 100 pounds 16-48-0 and 240 pounds per acre ammonium nitrate broadcast and worked into the soil before planting.

On July 3, 1964, the plants were starting to exert tassels when they were severely damaged by a hail storm in which 0.66 inch of precipitation was recorded. Between July 3 and July 24, 1964, less than one half inch of rain fell. Temperatures in excess of 100° F. were recorded for 7 days and in excess of 95° for 15 days of this period.

The plants were sampled on July 24, 1965, and placed in large walk-in drying ovens at 120 to 140° F. for one month. Plant parts were separated as soon after harvest as possible and replaced in the oven to continue the drying process.

Irrigated Location

On June 3, 1964 the plots were planted double and when the plants were 8 to 12 inches tall thinned to 16,340 plants per acre. The soil was an alluvial (Sarpy fine sandy loam) material, deposited by frequent overflows by the Kansas River. The plots were fertilized with 600 pounds of ammonium nitrate per acre. The study area was irrigated throughout the growing season.

The plots were harvested in the same manner as at the nonirrigated location. The time of harvest was September 6, 1964, when the corn grain was entering the dent stage of development. Many ears were lost in handling; consequently all ears were discarded and forage weights do not include the ears.

Total nitrogen, nitrate nitrogen and statistical analyses were made as previously described.

RESULTS AND DISCUSSION

1963 Experiment

Grain from the five hybrids--U.S.-523-W, A.E.S.-904-W, N-504, K-1859, and M-39--was harvested and an analysis of variance was made on the yield, components of yield, and grain nitrogen content.

Significant differences were found for grain yields for the five hybrids (Table 1)) No significant differences were found among spacings. The spacings were pooled into a composite mean for the hybrids (Table 2). Highly significant[1] differences among hybrids were found. U.S.-523-W and A.E.S.-904-W had significantly greater yield than M-39. The three yellow hybrids did not differ significantly. Yields ranged from 112.7 bushels per acre to 72.2 bushels per acre with an average of 98.0 bushels per acre.

Table 1. Analysis of variance for yield 1963 hybrid by row spacing test.

Source	Degrees of freedom	Mean square	F
Replication	3	390.9664	
Hybrids	4	2966.7590	8.48**[1]
Error (a)	12	349.9737	
Spacing	2	354.0206	1.87
Hybrid x spacing	8	193.3528	1.02
Error (b)	30	189.7919	

[1] The terms highly significant (**) and significant (*) will be used to designate probabilities of less than 0.01 and between 0.05 and 0.01 respectively.

Table 2. Yield, ears per plant, ear weight, and grain nitrogen of five hybrids in the 1963 experiment.

Hybrid	Yield Bu/a	Ears per plant	Ear weight Lbs/ear	Nitrogen %
U.S.-523-W	112.7a[1]	0.93a	0.53a	1.54 c
A.E.S.-904-W	107.6a	1.11a	0.42 b	1.57 c
N-504	101.6ab	0.96a	0.46ab	1.74 b
K-1859	95.9ab	0.93a	0.45ab	1.78 b
M-39	72.2 b	1.06a	0.32 c	1.95a
Average	98.0	1.00	0.44	1.715

[1] Values followed by a common letter were not significantly different at the 0.05 level of probability (Duncan, 1955).

No significant difference was found among hybrids relevant to the number of ears per plant (Table 3). All hybrids had essentially one ear per plant (Table 2).

Table 3. Analysis of variance for ears per plant in the 1963 experiment.

Source	Degrees of freedom	Mean square	F
Replication	3	0.064722	
Hybrids	4	0.080914	2.33
Error (a)	12	0.034718	
Spacing	2	0.034032	1.37
Hybrid x spacing	8	0.012926	<1
Error (b)	30	0.024753	

The analysis of variance showed highly significant differences among hybrids for ear weight (Table 4). The hybrids U.S.-523-W, N-504, and K-1859 had significantly heavier ears than M-39 while A.E.S.-904-W had lighter ears than U.S.-523-W but did not differ significantly from N-504 or K-1859 (Table 2).

Table 4. Analysis of variance for weight per ear in the 1963 experiment.

Source	Degrees of freedom	Mean square	F
Replication	3	0.009406	
Hybrids	4	0.070311	18.41**
Error (a)	12	0.003819	
Spacing	2	0.000922	< 1
Hybrid x spacing	8	0.003107	1.96
Error (b)	30	0.001588	

The analysis of variance for grain nitrogen (Table 5) again showed only significance among hybrids. A comparison of the means of the various hybrids showed M-39 had higher percent nitrogen than the other hybrids. N-504 and 1859 were higher than 523-W and 904-W (Table 2) with N-504 not differing from 1859 and 523-W not differing from 904-W.

Table 5. Analysis of variance for Kjeldahl nitrogen (from the grain in the experiment) 1963.

Source	Degrees of freedom	Mean square	F
Replication	3	0.019753	
Hybrids	4	0.344575	72.36**
Error (a)	12	0.004762	
Spacing	2	0.001385	<1
Hybrid x spacing	8	0.002750	<1
Error (b)	30	0.004141	

When reviewing the yield and components of yield data (Table 2) it may be observed that the two white hybrids yielded significantly more than the yellow hybrid M-39 with neither being different from the remaining two yellow hybrids. There was no difference in the number of ears per plant so all variation in yield may be attributed to the ear weight of each respective hybrid.

The grain nitrogen percentage was inversely related to the yield. The highest yielding hybrid produced the lowest yield of grain nitrogen (1.54 percent). The lowest yielding hybrid had the highest nitrogen concentration in the grain (1.95 percent). The yield varied 40.5 bushels while the grain nitrogen varied 0.41 percent.

1964 Experiment

In 1964, six single cross hybrids were used. No differences were found between row spacings for forage yields or differential nitrogen in any plant parts analyzed. Data from the two row spacings were pooled into a common mean for each hybrid for presentation.

Yield

The forage yield or weights of the vegetative portions of ten plants from the nonirrigated location are presented in Table 8. Analysis of variance showed highly significant differences among hybrids (Table 6). The hybrids containing the inbred line WF9 were in general the highest yielding hybrids. WF9 x C103 yielded significantly more than the three hybrids containing 38-11. Two components of variation, the general combining ability (GCA) effect and specific combining ability (SCA) effect, were analyzed (Table 6) and estimates of the GCA effects are presented in Table 7. No significance was found for SCA effects. With WF9 and C103 contributing 0.31 pounds and 0.19 pounds respectively to the mean, it is fairly well explained why the hybrids containing WF9 had the highest yield. The two inbred lines 38-11 and Hy2 had a negative contribution to the crosses and therefore exhibited a reduction in yield especially the in hybrid Hy2 x 38-11 (Table 8).

Highly significant differences were found among hybrids at the irrigated location (Table 7). The components of variance for the hybrids showed significant differences for GCA and SCA effects respectively. The inbred line, C103, exhibited positive GCA effects while the other lines showed different degrees of negative effects (Table 9). The line C103 when crossed with 38-11 had a negative SCA effect (Table 10) of sufficient magnitude to counteract the positive GCA effect of C103 which explains the relatively low yield of 38-11 x C103 (Table 8).

Table 6. Analysis for variance for dry forage weight of ten plants from the nonirrigated 1964 experiment.

Source	Degrees of freedom	Mean square	F
Replication	3	0.4367	
Hybrid	5	1.0200	62.16**
General combining ability	(3)	1.66208	10.14**
Specific combining ability	(2)	0.05880	< 1
Error (a)	15	0.1640	
Spacing	1	0.0000	< 1
Hybrid x spacing	5	0.520	8.25**
Error (b)	18	0.0063	

Table 7. Analysis for variance for dry forage weight of ten plants from the irrigated 1964 experiment.

Source	Degrees of freedom	Mean square	F
Replication	3	0.323	
Hybrid	5	0.908	6.98**
General combining ability	(3)	0.66184	5.09*
Specific combining ability	(2)	1.25488	9.65**
Error (a)	15	0.130	
Spacing	1	0.010	< 1
Hybrid x spacing	5	0.026	< 1
Error (b)	18	0.132	

Table 8. Forage yields of 10 plants at the irrigated and nonirrigated locations of the 1964 experiment.

Hybrid	Nonirrigated[1]	Irrigated[2]
	Lbs/10 plants	Lbs/10 plants
WF9 x C103	3.83a	3.55a
Hy2 x C103	3.36 bc	3.30ab
38-11 x C103	3.15abc	2.86 bc
WF9 x Hy2	3.60ab	2.68 c
WF9 x 38-11	3.15 bc	2.78 c
Hy2 x 38-11	2.83 c	3.11abc
Average	3.32	3.05

[1] The plants at the nonirrigated location formed no ears.

[2] Forage weights were taken without the ears.

Table 9. General combining ability effects for forage yields at the irrigated and nonirrigated locations in the 1964 experiment.

Inbred line	Nonirrigated	Irrigated
38-11	-0.415	-0.195
Hy2	-0.085	-0.025
C103	0.190	.285
WF9	0.310	-0.065

Table 10. Specific combining ability effects for forage yields at the irrigated location in the 1964 experiment.

Inbred line	Hy2	C103	WF9
38-11	0.29	-0.28	-0.01
Hy2		-0.01	-0.28
C103			0.29

Total Nitrogen Nonirrigated

Highly significant differences were found among hybrids for all plant parts in the nonirrigated test for total nitrogen content (Tables 11, 12, 13, 14 and 15). The GCA component of variance was also significant for all plant parts and the SCA component was significant for the lower culms, leaf sheaths, and leaf blades.

The hybrids containing 38-11 had the highest levels of total nitrogen followed by Hy2, C103 and WF9, respectively, in the whole plant samples (Table 15). Since SCA was not significant the variation among hybrids can be explained by the additive or GCA effects (Table 16). The estimates of GCA effects show WF9 and C103 contributed negatively to the total nitrogen content of the whole plant. The nitrogen level in the whole plant samples was intermediate between the lower culms and the upper culms, leaf sheaths and the leaf blades which indicate the level of nitrogen in the whole plant is determined largely by the nitrogen level of the lower culm.

The total nitrogen content of the lower culms was above that of the whole plant. The same hybrids which had high nitrogen on the whole plant basis also had high nitrogen in the lower culms. The main difference to note is the SCA effects were significant (Table 12). The hybrids 38-11 x C103 and WF9 x Hy2 had negative SCA effects (Table 18).

From Table 16 it is seen that the upper culm of some of the hybrids reacted somewhat differently from the above mentioned analyses. GCA effects were significant (Table 13) and SCA effects for total nitrogen in the upper culms were nonsignificant. Estimates for GCA effects were made and presented in Table 17. As shown the inbred lines Hy2 and C103 had a negative contribution to the nitrogen level, while 38-11 and WF9had positive contributions to the nitrogen level. WF9 x 38-11 had a significantly higher nitrogen level than the four lowest hybrids which did not differ from one another.

The leaf sheaths had nitrogen levels which averaged1.083 percent and ranged from 0.868 to 1.227 percent. Analysis of components of variance showed both the GCA and the SCA effects significant (Table 14). Estimates of the GCA effects revealed 38-11 as having the only positive effect on total nitrogen (Table 17). Reviewing the data presented in Table 16, it can be seen that this did have a significant effect on the nitrogen level in the leaf sheaths of the hybrids containing 38-11 even though SCA effects were significant (Table 18). The 38-11 x C103 cross had a negative SCA effect but the negative effect was not of sufficient magnitude that this hybrid differed from the other two containing 38-11.

The range in nitrogen content for the leaf blades was only 0.3 percent. Hybrids were highly significant, with GCA and SCA effects both being significant (Table 15). 38-11 had the largest positive GCA effect followed by Hy2. C103 had a relatively large negative GCA value and WF9 was also negative (Table 17). SCA effects were negative for the hybrids 38-11 x C103 and WF9 x Hy2 (Table 18). WF9 x C103 and Hy2 x C103 did not differ from one another and Hy2 x C103 and 38-11 x C103 did not differ. The other individual hybrids were significantly different with Hy2 x 38-11 having the highest nitrogen level.

Table 11. Analysis of variance for total nitrogen from whole plants at the nonirrigated location of the 1964 experiment.

Source	Degrees of freedom	Mean square	F
Replication	3	0.0887	
Hybrids	5	0.5246	18.41**
General combining ability	(3)	0.8182	28.71**
Specific combining ability	(2)	0.0816	2.86
Error (a)	15	0.0285	
Spacing	1	0.0060	< 1
Hybrid x spacing	5	0.0134	1.38
Error (b)	18	0.0097	

Table 12. Analysis of variance for total nitrogen from the lower culm at the nonirrigated location of the 1964 experiment.

Source	Degrees of freedom	Mean square	F
Replication	3	0.9156	
Hybrids	5	1.1964	8.32**
General combining ability	(3)	1.6370	11.39**
Specific combining ability	(2)	0.5311	3.70*
Error (a)	15	0.1437	
Spacing	1	0.0030	<1
Hybrid x spacing	5	0.0246	<1
Error (b)	18	0.1031	

Table 13. Analysis of variance for total nitrogen from upper culms at the nonirrigated location of the 1964 experiment.

Source	Degrees of freedom	Mean square	F
Replication	2	0.0605	
Hybrids	5	1.2474	7.59**
General combining ability	(3)	2.16714	13.18**
Specific combining ability	(2)	0.24306	1.48
Error (a)	10	0.1644	
Spacing	1	0.0160	< 1
Hybrid x spacing	5	0.0562	< 1
Error (b)	11	0.1327	

Table 14. Analysis of variance for total nitrogen from leaf sheaths at the nonirrigated location of the 1964 experiment.

Source	Degree of freedom	Mean square	F
Replication	3	0.0610	
Hybrids	5	0.1720	22.05**
General combining ability	(3)	0.25624	32.85**
Specific combining ability	(2)	0.04704	6.03*
Error (a)	15	0.0078	
Spacing	1	0.0020	< 1
Hybrid x spacing	5	0.0026	< 1
Error (b)	18	0.0077	

Table 15. Analysis of variance for total nitrogen from leaf blades at the nonirrigated location of the 1964 experiment.

Source	Degrees of freedom	Mean square	F
Replication	3	0.0077	
Hybrids	5	0.1018	9.51**
General combining ability	(3)	0.16160	1514.92**
Specific combining ability	(2)	0.01280	119.96**
Error (a)	15	0.00107	
Spacing	1	0.0070	1.94
Hybrid x spacing	5	0.0014	< 1
Error (b)	18	0.0036	

Table 16. Total nitrogen as determined by the Gunning-Kjeldahl method from the whole plants and component parts at the nonirrigated location in the 1964 experiment.

Hybrid	Whole plant	Lower culms	Upper culms	Leaf sheaths	Leaf blades
	%	%	%	%	%
WF9 x C103	1.682c	2.270b	1.296bc	0.991bc	1.792e
Hy2 x C103	1.924bc	2.751ab	1.106c	1.017b	1.814de
38-11 x C103	2.08ab	2.663b	1.844ab	1.175a	1.845d
WF9 x Hy2	1.736c	2.187b	1.091c	0.868c	1.914c
WF9 x 38-11	2.167ab	2.655b	2.323a	1.227a	1.997b
Hy2 x 38-11	2.342a	3.266a	1.641bc	1.223a	2.080a
Average	1.988	2.632	1.578	1.083	1.907

Table 17. Estimates of general combining ability effects for total nitrogen in the plant parts at the nonirrigated location in the 1964 experiment.

Inbred line	Whole plant	Lower culms	Upper culms	Leaf sheaths	Leaf blades
38-11	0.3120	0.344	0.57875	0.18725	0.1005
Hy2	0.0180	0.154	-0.40625	-0.07125	0.0435
C103	-0.1395	-0.106	-0.20225	-0.03375	-0.1350
WF9	-0.1905	-0.392	0.02975	-0.08225	-0.0090

Table 18. Estimates of specific combining ability effects for total nitrogen in the plant parts at the nonirrigated location in the 1964 experiment.

Inbred line	Plant part	Hy2	C103	WF9
38-11	Lower culms	0.1360	-0.2070	0.0710
	Leaf sheaths	0.0235	-0.0620	0.0385
	Leaf blades	0.0290	-0.0275	-0.0015
Hy2	Lower culms		0.0710	-0.2070
	Leaf sheaths		0.0385	-0.0620
	Leaf blades		-0.0015	-0.0275
C103	Lower culms			0.1360
	Leaf sheaths			0.0235
	Leaf blades			0.0290

Total Nitrogen Irrigated

Differences in total nitrogen among hybrids for the whole plant samples were significant (Table 19). Duncan's New Multiple Range Test showed the hybrids 38-11 x C103 and Hy2 x 38-11 to have a significantly higher nitrogen level than WF9 x C103 (Table 24). The remaining hybrids did not differ from the high or low hybrids.

Analysis of the components of variance (Table 19) for the hybrids showed the variation to be caused by the GCA effects. Estimates of the GCA effects show 38-11 again to be the inbred line contributing to a high total nitrogen level (Table 25). The lines Hy2 and C103 were intermediate and WF9 contributed the least amount to the nitrogen level.

For the lower culms the hybrids were highly significant and in addition there was a significant interaction for hybrid by spacing (Table 20). There was a reversal of the spacing effects for the hybrids WF9 x Hy2 and WF9 x 38-11 in favor of the 20-inch row spacing. The other four hybrids had either equal effects for spacing or a slight advantage for the 40-inch row spacing. For this reason the spacing effects were not significant and the interaction was obtained.

The hybrids Hy2 x C103 and 38-11 x C103 had significantly higher nitrogen levels in the lower culms than WF9 x 38-11 and WF9 x C103 (Table 24). WF9 x Hy2 x 38-11 did not differ from either the high hybrids or the low hybrids. The GCA effects were highly significant (Table 21) and the estimates of the GCA effects showed 38-11 to have a slight negative effect along with WF9 which had a considerable negative effect (Table 25). Hy2 had a rather large positive effect and C103 was positive with lesser magnitude.

The hybrid combinations Hy2 x 38-11 and WF9 x C103 had negative SCA effects and all other crosses showed positive effects (Table 26).

The low value for total nitrogen of the WF9 x C103 hybrid was caused by the negative combining ability effects both GCA and SCA of WF9 and SCA of WF9 x C103. The low value for WF9 x 38-11 was caused by the GCA effects of the two inbred lines both being negative. The high value for Hy2 x C103 was a combination of the two positive GCA effects and a positive SCA effect.

The upper culms did not vary significantly between spacings nor among hybrids as shown in Table 24. The average nitrogen in the upper culm portion of the plant for all hybrids was 0.516 percent (Table 21).

The leaf sheath portion of the plant exhibited no significance in the analysis of variance (Table 22). The average total nitrogen content was 0.553 percent (Table 24).

There were differences among hybrids for total nitrogen in the leaf blades (Table 23). The hybrids containing 38-11 did not differ from one another and WF9 x 38-11 had a higher total nitrogen content than the three lowest hybrids (Table 24). Both the GCA and SCA components of variance for the hybrids were significant. Estimates of GCA effects were highest for the inbred line 38-11 and WF9 was also positive (Table 25). Hy2 and C103 were about equally negative. The estimates of SCA effects (Table 26) were positive for Hy2 x 38-11 and WF9 x C103. The SCA effects for the remaining four hybrids were all negative. In all cases, however, rather small values were obtained for the estimates of SCA effects. The GCA effects apparently had more influence in the nitrogen level of the leaf blades than the SCA effects.

Table 19. Analysis of variance for total nitrogen from whole plants at the irrigated location of the 1964 experiment.

Source	Degrees of freedom	Mean square	F
Replication	3	0.0410	
Hybrids	5	0.0550	3.87*
General combining ability	(3)	0.0642	4.52*
Specific combining ability	(2)	0.0409	2.88
Error (a)	15	0.0142	
Spacing	1	0.0030	< 1
Hybrid x spacing	5	0.0024	< 1
Error (b)	18	0.0045	

Table 20. Analysis of variance for total nitrogen from lower culms at the irrigated location of the 1964 experiment.

Source	Degrees of freedom	Mean square	F
Replication	3	0.1553	
Hybrids	5	0.3956	6.33**
General combining ability	(3)	0.4600	7.36**
Specific combining ability	(2)	0.2994	4.79*
Error (a)	15	0.0625	
Spacing	1	0.0340	3.62
Hybrid x spacing	5	0.0268	2.85*
Error (b)	18	0.0094	

Table 21. Analysis of variance for total nitrogen from upper culms at the irrigated location of the 1964 experiment.

Source	Degrees of freedom	Mean square	F
Replication	3	0.0160	
Hybrids	5	0.0476	2.38
Error (a)	15	0.0200	
Spacing	1	0.0040	< 1
Hybrid x spacing	5	0.0265	2.43
Error (b)	18	0.0109	

Table 22. Analysis of variance for total nitrogen from leaf sheaths at the irrigated location of the 1964 experiment.

Source	Degrees of freedom	Mean square	F
Replication	3	0.0183	
Hybrids	5	0.0092	1.96
Error (a)	15	0.0047	
Spacing	1	0.0000	< 1
Hybrid x spacing	5	0.0008	< 1
Error (b)	18	0.0047	

Table 23. Analysis of variance for total nitrogen from leaf blades at the irrigated location of the 1964 experiment.

Source	Degrees of freedom	Mean square	F
Replication	3	0.0323	
Hybrids	5	0.2774	15.58**
General combining ability	(3)	0.4585	25.76**
Specific combining ability	(2)	0.0673	3.78*
Error (a)	15	0.0178	
Spacing	1	0.0260	2.20
Hybrid x spacing	5	0.0134	1.14
Error (b)	18	0.0118	

Table 24. Total nitrogen content of whole plant samples and component plant parts of the six single-cross hybrids at the irrigated location of the 1964 experiment.

Hybrid	Whole plant	Lower culms	Upper culms	Leaf sheaths	Leaf blades
		Percent N			
WF9 x C103	0.738b	0.712b	0.427a	0.558a	1.288bc
Hy2 x C103	0.904ab	1.266a	0.506a	0.491a	1.096c
38-11 x C103	0.982a	1.207a	0.622a	0.582a	1.420ab
WF9 x Hy2	0.888ab	1.083ab	0.483a	0.541a	1.275bc
WF9 x 38-11	0.911ab	0.790b	0.463a	0.570a	1.629a
Hy2 x 38-11	0.936a	1.033ab	0.596a	0.578a	1.485ab
Average	0.893	1.015	0.516	0.553	1.366

Table 25. Estimates of general combining ability effects for total nitrogen in the plant parts at the irrigated location in the 1964 experiment.

Inbred line	Whole plant	Lower culms	Leaf blades
38-11	0.07475	-0.00775	0.21875
Hy2	0.02425	0.16825	-0.12025
C103	-0.02775	0.06975	-0.14625
WF9	-0.07125	-0.23025	0.04775

Table 26. Estimates of specific combining ability effects for total nitrogen in the plant parts at the irrigated location in the 1964 experiment.

Inbred line	Plant part	Hy2	C103	WF9
38-11	Lower culms	-0.1426	0.1298	0.0128
	Leaf blades	0.021	-0.018	-0.003
Hy2	Lower culms		0.0128	0.1298
	Leaf blades		-0.003	-0.018
C103	Lower culms			-0.1426
	Leaf blades			0.021

Nitrate Nitrogen Nonirrigated

The whole plant samples taken from the nonirrigated location showed differences among hybrids for nitrate content (Table 27). Of the two components of variance the GCA effects were significant. The nitrate levels ranged from 0.769 percent down to 0.504 percent with an average of 0.639 percent.

The hybrid with the highest nitrate level was 38-11 x C103 (Table 32). It had a higher level of nitrate than the lowest four and was not different from the second highest hybrid. It may be noted that the three highest hybrids all contained 38-11. WF9 is present in two of the three lowest hybrids. The lines C103 and Hy2 are not as obviously segregated into one area or another.

Estimates of the GCA effects (Table 33) verify the above observations. The line 38-11 contributed most to the high nitrate levels and WF9 contributed least to the accumulation of nitrate. The lines Hy2 and C103 were intermediate between 38-11 and WF9.

For the lower culms from the nonirrigated location the analysis of variance (Table 28) showed the hybrids, GCA and SCA to have significant differences. The nitrate level for the lower culms was ranked in approximately the same order as for the whole plant (Table 32). The nitrate levels were more than three times higher than the whole plants. The range of nitrate was from 2.568% to 1.516% with 1.981% as the average across hybrids.

The estimates of GCA effects showed essentially the same relationship among inbred lines except Hy2 contributes somewhat more to the accumulation of nitrate nitrogen than it did in the whole plant sample (Table 33).

Table 27. Analysis of variance for nitrate nitrogen from the whole plant samples at the nonirrigated location of the 1964 experiment.

Source	Degrees of freedom	Mean square	F
Replication	3	0.0530	
Hybrid	5	0.0965	6.39**
General combining ability	(3)	0.1536	10.15**
Specific combining ability	(2)	0.01104	< 1
Error (a)	15	0.0151	
Spacing	1	0.011	2.12
Hybrid x spacing	5	0.003	< 1
Error (b)	18	0.0052	

Table 28. Analysis of variance for nitrate nitrogen from lower culm at the nonirrigated location of the 1964 experiment.

Source	Degrees of freedom	Mean square	F
Replication	3	1.0210	
Hybrid	5	1.1434	9.43**
General combining ability	(3)	2.2624	18.67**
Specific combining ability	(2)	0.5992	4.95*
Error (a)	15	0.1212	
Spacing	1	0.0130	< 1
Hybrid x spacing	5	0.0412	< 1
Error (b)	18	0.0914	

Table 29. Analysis of variance for nitrate nitrogen from upper culm at the nonirrigated location of the 1964 experiment.

Source	Degrees of freedom	Mean square	F
Replication	2	0.0033935	
Hybrid	5	0.0187374	3.23
Error (a)	10	0.0057931	
Spacing	1	0.009572	1.51
Hybrid x spacing	5	0.0002788	< 1
Error (b)	11	0.0063454	

Table 30. Analysis of variance for nitrate nitrogen from leaf sheats at the nonirrigated location of the 1964 experiment.

Source	Degrees of freedom	Mean square	F
Replication	3	0.027144	
Hybrid	5	0.032242	4.72**
General combining ability	(3)	0.029176	4.27*
Specific combining ability	(2)	0.036656	5.37*
Error (a)	15	0.006826	
Spacing	1	0.001073	0.31
Hybrid x spacing	5	0.003682	1.06
Error (b)	18	0.003488	

Table 31. Analysis of variance for nitrate nitrogen from leaf blades at the nonirrigated location of the 1964 experiment.

Source	Degrees of freedom	Mean square	F
Replication	3	0.001004	
Hybrid	5	0.007845	6.87**
General combining ability	(3)	0.0021160	22.78**
Specific combining ability	(2)	0.0009360	10.08**
Error (a)	15	0.001393	
Spacing	1	0.000028	0.47
Hybrid x spacing	5	0.000525	1.78
Error (b)	18	0.001058	

Table 32. Nitrate nitrogen content of whole plant samples and the component parts of the six single-cross hybrids from the nonirrigated location of the 1964 experiment.

Hybrid	Whole plant	Lower culms	Upper culms	Leaf sheaths	Leaf blades
	Percent NO_3-N				
WF9 x C103	0.509c	1.632bc	0.079a	0.020b	0.037c
Hy2 x C103	0.661b	2.159ab	0.067a	0.054ab	0.052bc
38-11 x C103	0.722ab	1.999bc	0.175a	0.020b	0.044c
WF9 x Hy2	0.504c	1.516c	0.115a	0.009b	0.042c
WF9 x 38-11	0.670b	2.011abc	0.212a	0.166a	0.060b
Hy2 x 38-11	0.769a	2.568a	0.139a	0.116ab	0.076a
Average	0.639	1.981	0.131	0.064	0.052

Table 33. Estimates of general combining ability effects for nitrate nitrogen in the whole plant and component parts at the nonirrigated location of the 1964 experiment.

Inbred line	Whole plant	Lower culms	Leaf sheaths	Leaf blades
38-11	0.12175	0.31775	0.05475	0.01225
Hy2	0.00825	0.15025	-0.00675	0.00725
C103	-0.01275	-0.07625	-0.04925	-0.01125
WF9	-0.11725	-0.39175	0.00125	-0.00825

Table 34. Estimates of specific combining ability for nitrate nitrogen in the component plant parts at the nonirrigated location of the 1964 experiment.

Inbred line	Plant part	Hy2	C103	Wf9
38-11	Lower culms	0.1192	-0.2234	0.1042
	Leaf sheaths	0.0039	-0.0497	0.0458
	Leaf blades	0.0047	-0.0089	0.0042
Hy2	Lower culms		0.1042	-0.2234
	Leaf sheaths		0.0458	-0.0497
	Leaf blades		0.0042	-0.0089
C103	Lower culms			0.1192
	Leaf sheaths			0.0039
	Leaf blades			0.0047

The estimates of SCA effects seem to contribute more to the extremes than to the intermediate levels of nitrate. From Table 34 it may be noted that the SCA effect of Hy2 x 38-11 was positive and from Table 33 the two GCA effects for Hy2 and 38-11 were also positive, which explains the high level (2.568 percent) that was present in the lower culms of that particular hybrid. In contrast to this the SCA effect for WF9 x Hy2 was large enough and negative to rank this hybrid lowest in nitrate content even though the GCA effect for Hy2 was positive. For the other hybrids the GCA and SCA effects cancelled one another to varying degrees to yield the intermediate levels of nitrate.

No differences were found among hybrids or between spacings for the nitrate content of the upper culm portion of the plant (Table 29). The content ranged from 0.212 to 0.067 percent and averaged 0.131 percent across all hybrids (Table 32).

From the leaf sheath portion of the plant the nitrate content of the hybrids were found to differ and the GCA and SCA effects were significant (Table 30). As shown by Table 33 an estimate of the GCA effect for the inbred line 38-11 was rather large compared to the other lines. The cross WF9 x 38-11 had the highest nitrate level (Table 32). This was caused by the GCA effects which were positive for both WF9 and 38-11 and the SCA effect (Table 34) which was also positive for the combination of these two particular lines. The SCA effects for 38-11 x C103 and WF9 x Hy2 were the only two crosses that were found to be negative.

The main differences in the sheaths from the other plant parts was in the GCA effects of the line WF9 which were rather large negative values for the whole plants and lower culms and the GCA effect was small in the positive direction for the sheaths. The percent nitrate involved in the sheaths was rather small.

The analysis of variance for nitrate content of the leaf blades at the nonirrigated location showed differences among hybrids and showed these differences to be due to both the GCA and SCA effects (Table 31). The hybrid Hy2 x 38-11 had a higher level of nitrate than all other hybrids (Table 32). WF9 x 38-11 had a higher level of nitrate than the lowest three hybrids but did not differ from Hy2 x C103 which did not differ from the lower three.

The estimates of GCA effects (Table 33) shows that 38-11 contributed most to the nitrate level of its hybrids and C103 contributed least to nitrate accumulation. The estimates of the SCA effects showed 38-11 in combination with C103 and WF9 in combination with Hy2 as having had a negative contribution to the nitrate level (Table 34).

Nitrate Nitrogen Irrigated

Nitrate nitrogen content of the hybrids at the irrigated location was significantly different (Table 35). The combining ability analysis (Table 35) showed both GCA and SCA effects significant. The hybrids 38-11 x C103 and WF9 x Hy2 had a higher percent nitrate nitrogen than WF9 x 38-11 and WF9 x C103 (Table 30). Hy2 x C103 and Hy2 x 38-11 did not differ from the two highest hybrids nor from WF9 x 38-11 which was immediately below. WF9 x C103 had the lowest nitrate level of the six hybrids.

Estimates of the GCA effects (Table 41) showed 38-11 and Hy2 contributing about equally to the nitrate nitrogen content of the whole plant samples. WF9 was the inbred line most responsible for the lower levels of nitrate. Estimates of the SCA effects (Table 42) show positive effects for 38-11 x C103 and WF9 x Hy2. The SCA effects for all other hybrids were negative. The SCA effects were great enough to cause a random distribution of the inbred lines across the range of nitrate levels. As an example (Table 40) C103 was involved in the cross having the highest percent nitrate at an intermediate level and in the hybrid having the lowest level of nitrate. The same circumstance was found for all other inbred lines in this experiment.

In the lower culm samples differences were found among hybrids for percent nitrate nitrogen (Table 36). Analysis for GCA and SCA effects were also found to be significant. It may be observed from Table 40 that the hybrids may be ranked in the same general order for nitrate content in the lower culms as they were in the whole plant samples. 38-11 x C103 and Hy2 x C103 had a higher percent nitrate than WF9 x C103. The two highest hybrids did not differ from WF9 x Hy2, Hy2 x 38-11 and WF9 x 38-11 which were not different from WF9 x C103, the lowest.

Estimates of the GCA effects (Table 41) show 38-11, Hy2 and C103 had positive contributions to the nitrate level and WF9 had a negative contribution to the nitrate level in the lower culms. Estimates of the SCA effects (Table 42) indicate Hy2 x 38-11 and WF9 x C103 had negative effects when the inbred lines involved were in these particular combinations.

The analysis of variance (Table 37) for the upper culms showed no significance for hybrids nor spacings. The average nitrate content across all hybrids was 0.023 percent (Table 40).

No significance was found for the leaf sheaths at the irrigated location (Table 38). The average nitrate content was 0.004 percent for all hybrids (Table 40).

Again, no significant differences among hybrids were found for the leaf blade portion of the plant (Table 39). The average level of nitrate nitrogen found in the leaf blades was 0.003 percent.

Table 35. Analysis of variance for nitrate nitrogen from whole plants at the irrigated location of the 1964 experiment.

Source	Degrees of freedom	Mean square	F
Replication	3	0.0687	
Hybrid	5	0.0502	21.55**
General combining ability	(3)	0.041504	17.79**
Specific combining ability	(2)	0.062368	26.73**
Error (a)	15	0.00233	
Spacing	1	0.0000	< 1
Hybrid x spacing	5	0.0088	1.01
Error (b)	18	0.0087	

Table 36. Analysis of variance for nitrate nitrogen from the lower culms at the irrigated location of the 1964 experiment.

Source	Degrees of freedom	Mean square	F
Replication	3	0.2667	
Hybrid	5	0.4424	4.34*
General combining ability	(3)	0.47016	4.62*
Specific combining ability	(2)	0.39832	3.91*
Error (a)	15	0.1019	
Spacing	1	0.0040	< 1
Hybrid x spacing	5	0.0150	1.35
Error (b)	18	0.0111	

Table 37. Analysis of variance for nitrate nitrogen from the upper culms at the irrigated location of the 1964 experiment.

Source	Degrees of freedom	Mean square	F
Replication	3	0.0030	
Hybrid	5	0.0014	1.40
Error (a)	15	0.0010	
Spacing	1	0.0000	< 1
Hybrid x spacing	5	0.0008	< 1
Error (b)	18	0.0009	

Table 38. Analysis of variance for nitrate nitrogen from the leaf sheaths at the irrigated location of the 1964 experiment.

Source	Degrees of freedom	Mean square	F
Replication	3	0.000015	
Hybrid	5	0.000011	1.38
Error (a)	15	0.000008	
Spacing	1	0.000000	< 1
Hybrid x spacing	5	0.000018	2.57
Error (b)	18	0.000007	

Table 39. Analysis of variance for nitrate nitrogen from the leaf blades at the irrigated location of the 1964 experiment.

Source	Degrees of freedom	Mean square	F
Replication	3	0.000009	
Hybrid	5	0.000024	2.40
Error (a)	15	0.000010	
Spacing	1	0.000017	1.21
Hybrid x spacing	5	0.000009	< 1
Error (b)	18	0.000014	

Table 40. Nitrate nitrogen in the vegetative portions of corn at the irrigated location in the 1964 experiment.

Hybrid	Whole plant	Lower culms	Upper culms	Leaf sheaths	Leaf blades
	Percent NO_3-N				
WF9 x C103	0.102 c	0.363 b	0.004a	0.004a	0.005a
Hy2 x C103	0.266ab	0.935a	0.020a	0.003a	0.003a
38-11 x C103	0.327a	0.950a	0.044a	0.004a	0.005a
WF9 x Hy2	0.288a	0.818ab	0.023a	0.005a	0.002a
WF9 x 38-11	0.208b	0.527ab	0.024a	0.003a	0.001a
Hy2 x 38-11	0.264ab	0.774ab	0.024a	0.006a	0.005a
Average	0.242	0.728	0.023	0.004	0.003

Table 41. Estimates of general combining ability for nitrate nitrogen in the whole plant and lower culm portion at the irrigated location of the 1964 experiment.

Inbred line	Whole plant	Lower culms
38-11	0.03575	0.03375
Hy2	0.04525	0.17175
C103	-0.01625	0.03225
WF9	-0.06475	-0.23775

Table 42. Estimates of specific combining ability for nitrate nitrogen in the whole plant and lower culm portion at the irrigated location of the 1964 experiment.

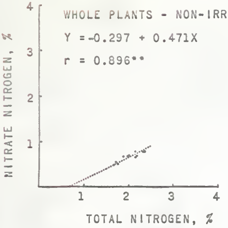
Inbred line	Plant part	Hy2	C103	WF9
38-11	Whole plant X_1	-0.0595	0.0650	-0.0055
	Lower culms X_2	-0.1594	0.1562	0.0032
Hy2	Whole plant X_1		-0.0055	0.0650
	Lower culms X_2		0.0032	0.1562
C103	Whole plant X_1			-0.0595
	Lower culms X_2			-0.1594

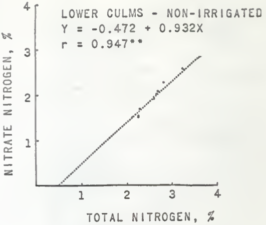
Relation between Total Nitrogen and Nitrate Nitrogen

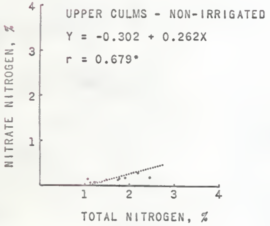
Nonirrigated Location

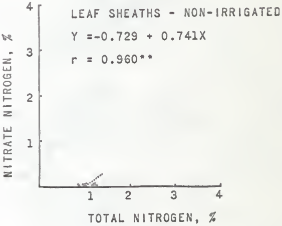
The relation between total nitrogen and nitrate nitrogen for all plant parts is shown in Fig. 1. From the whole plant samples it was found that as the total nitrogen increased between 1.480 and 2.545 percent, the limits of this experiment, the nitrate nitrogen also increased. The relationship was linear with a slope of 0.471. The line intercepts the total nitrogen axis at 0.631 percent. This would indicate a level of 0.631 percent total nitrogen is reached before any nitrate nitrogen is accumulated. At levels greater than 0.631 percent total nitrogen 47.1 percent of the nitrate entering the plant remains as nitrate. The foregoing statements may be true if the relationship is the same as between the limits 1.480 and 2.545 percent total nitrogen. To clearly define a point of inflection, that point at which nitrate nitrogen begins to accumulate, observations both above and

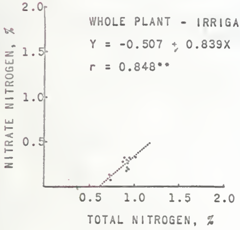
Fig. 1. Relation between percent total nitrogen and percent nitrate nitrogen in the plant parts of the 1964 experiment.

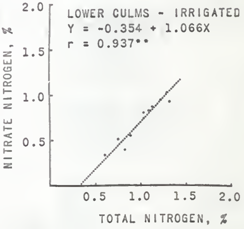

WHOLE PLANTS - NON-IRRIGATED
Y =-0.297 + 0.471X
r = 0.896**
NITRATE NITROGEN, %
TOTAL NITROGEN, %
1
2
3
4


LOWER CULMS - NON-IRRIGATED
Y = -0.472 + 0.932X
r = 0.947**
NITRATE NITROGEN, %
TOTAL NITROGEN, %
1
2
3
4


UPPER CULMS - NON-IRRIGATED
Y = -0.302 + 0.262X
r = 0.679*
NITRATE NITROGEN, %
TOTAL NITROGEN, %
1
2
3
4


LEAF SHEATHS - NON-IRRIGATED
Y =-0.729 + 0.741X
r = 0.960**
NITRATE NITROGEN, %
TOTAL NITROGEN, %
1
2
3
4


WHOLE PLANT - IRRIGATED
Y = -0.507 + 0.839X
r = 0.848**
NITRATE NITROGEN, %
TOTAL NITROGEN, %
0.5
1.0
1.5
2.0


LOWER CULMS - IRRIGATED
Y = -0.354 + 1.066X
r = 0.937**
NITRATE NITROGEN, %
TOTAL NITROGEN, %
0.5
1.0
1.5
2.0

below it would be needed. The data would have to be continuous and include the limits of this experiment.

The lower culms had a similar relation of nitrate nitrogen to total nitrogen. The experiment covered the area between 1.579 percent to 3.725 percent total nitrogen. The slope of the line was 0.932 which means that within the limits of the experiment 93.2 percent of the nitrate nitrogen entering the lower culms remains as nitrate nitrogen. If this relationship holds true for all values of total nitrogen, nitrate nitrogen would not accumulate below 0.506 percent total nitrogen.

In the nonirrigated upper culms when nitrate nitrogen was plotted against total nitrogen all observations were in the range of 0.9 to 2.4 percent total nitrogen. This range appeared to include the inflection point of the curve. The regression line of nitrate nitrogen on total nitrogen was calculated for total nitrogen values greater than 1.508 percent. A positive slope of 0.262 indicated that 26.2 percent of the nitrogen in the upper culms remains as nitrate nitrogen when the total nitrogen percentage exceeds the level of 1.508 percent total nitrogen.

Similar results were obtained for the leaf sheaths. The regression line indicates that for total nitrogen contents greater than 0.984 percent, 74 percent of the nitrate nitrogen was accumulated as nitrate. Although the regression coefficient was highly significant, the regression line was based on a rather small number of observations in a range of 0.5 percent total nitrogen.

When nitrate nitrogen was plotted against total nitrogen for the leaf blades no accumulation of nitrate was noted. All values of total nitrogen fell between 1.7 and 2.2 percent. All nitrate nitrogen values were less than 0.1 percent.

Irrigated Location

Nitrate nitrogen was plotted against total nitrogen for the whole plant samples at the irrigated location and presented in Fig. 1. The smallest alue of total nitrogen found in the whole plant samples was 0.645 percent and the largest was 1.132 percent. For values less than 0.604 percent total nitrogen probably no nitrate will accumulate. For values greater than 0.604 percent total nitrogen 83.9 percent remained in the vegetative plant tissue as nitrate nitrogen. The production of grain at the irrigated location required the translocation of relatively large amounts of protein nitrogen to the ear. Benne et al. (1964) found that 64 percent of the total nitrogen entering the aerial portions of the plant ultimately entered the ear. Considering this work, it was concluded that as the nitrate nitrogen was reduced it was translocated to the grain. Because the ears were not included in the nitrogen determinations, the total nitrogen vs. nitrate nitrogen ratio found in the whole plant samples was relatively larger than at the nonirrigated location.

For the lower culms a regression line was computed with a slope of 1.066. Since it is impossible for nitrate to accumulate faster than the level of total nitrogen increases, a t-test was performed. The actual slope was 1.066 ± 0.118, which is not significantly different from 1.000.

The remaining plant parts (the upper culms, leaf sheaths, and leaf blades) had nitrate nitrogen levels below 0.05 percent.

The range of total nitrogen was from 0.3 to 0.8 percent for the upper culm samples. These values were too low for any accumulation of nitrate to occur.

The range for the leaf sheath samples was from 0.4 to 0.7 percent total nitrogen. The upper limit of the data was approaching the point of inflection found at the nonirrigated location.

The total nitrogen for the leaf blades ranged from 1.0 to 1.7 percent. As at the nonirrigated location, no nitrate accumulated in the leaf blades.

The point at which nitrate nitrogen first started to accumulate did not differ markedly from the irrigated location to the nonirrigated location. The corn at the irrigated location appeared to start accumulating nitrate nitrogen at 0.604 percent total nitrogen as compared to 0.631 percent total nitrogen per whole plant at the nonirrigated location.

The data for the other plant parts were in general agreement with those presented by Hanway (1962) except that Hanway's data were somewhat lower. Hanway presented data showing a total nitrogen increase with no accumulation of nitrate up to a certain point of inflection, beyond which point a constant percent of the increased total nitrogen remains as nitrate nitrogen.

SUMMARY AND CONCLUSIONS

An experiment was conducted in 1963 to determine if hybrids differ in their response to changes in row spacing. Five double-cross hybrids were used, consisting of two white and three yellow hybrids. No differences were found among the 20-, 30-, and 40-inch row spacings. Interactions between hybrids and row spacings did not exist. Significant differences were found among the five hybrids for yield. The two white hybrids, A.E.S. 523-W and A.E.S. 904-W, were the highest yielding hybrids and yielded significantly more than Crow's multiple-eared hybrid, M-39,

There were no differences found among the hybrids for the number of ears per plant. An average of one ear per plant for all hybrids was found. Differences in yield were attributed to the differences in ear weight. The highest yielder, A.E.S. 523-W, also had the heaviest ears--0.53 pounds per ear. The ear weight of the lowest yielding hybrid, M-39, was 0.32 pounds per ear. The protein nitrogen in the grain was inversely proportional to the yield.

In 1964 under conditions of severe drought preceded by a severe hail storm, plant samples were taken at the stage of development when a farmer might harvest the crop for forage purposes and analyzed for vegetative forage yield, total nitrogen, and nitrate nitrogen in the whole plant, lower culms, upper culms, leaf sheaths, and leaf blades. No differences were found between spacings. The forage yields at the irrigated location were lower than at the nonirrigated location because the ears were not included at the irrigated location and no ears were formed at the nonirrigated. Significant differences were found among hybrids at both locations.

Significant differences among hybrids were found for total nitrogen from the plant parts at both the nonirrigated and irrigated (excluding the upper culms and the leaf sheaths) locations. In general, the inbred lines (38-11, Hy2, C103, and WF9), when incorporated in the hybrids, contributed respectively to the high level of total nitrogen. This was the inverse order of the forage yields.

The same relation held true for nitrate nitrogen as for total nitrogen. The total nitrogen accumulated per acre by the different hybrids did not vary over 3 pounds nitrogen per acre. A difference of only 0.6 pound assimilated nitrogen per acre was found. The differences found among the hybrids in the nitrate nitrogen concentrations within the plants were the result of the failure or inability to reduce and assimilate nitrate nitrogen.

Within the limits of this experiment any increase in total nitrogen in the lower culms was nitrate nitrogen at either location. Nitrogen determinations from whole plant samples showed 83.9 percent of the total nitrogen in the vegetative portion was nitrate nitrogen at the irrigated location while the value was 47.1 percent at the nonirrigated location. It was concluded that nitrate nitrogen was reduced at the irrigated location and translocated to the grain. The total nitrogen level was lowered by the amount of nitrogen in the grain and increased the nitrate-total nitrogen ratio. The calculated points at which nitrate began to accumulate were comparable. The data indicated that nitrate nitrogen was absorbed irrespective of the plant's needs. All nitrate was reduced below 0.604 to 0.631 percent total nitrogen. At this point equilibrium was reached and only a portion of the nitrate was reduced.

The upper culms, leaf sheaths, and leaf blades did not accumulate nitrate in meaningful quantities.

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CORN (ZEA MAYS L.) HYBRIDS AS AFFECTED BY ROW SPACING: I. GRAIN YIELDS, COMPONENTS OF YIELD, AND GRAIN NITROGEN OF FIVE DOUBLE CROSS HYBRIDS. II. TOTAL NITROGEN AND NITRATE NITROGEN IN DIFFERENT PLANT PARTS OF SIX SINGLE CROSS HYBRIDS.

by

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B.S., Ft. Hays Kansas State College, 1963

AN ABSTRACT OF A THESIS

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Corn, a popular grain and forage crop, is commonly grown in 36- to 40-inch rows. With the development of suitable mechanized equipment, narrower row spacings are possible.

In 1963 an experiment was initiated to evaluate the effects of 20-, 30-, and 40-inch row spacings on the grain yield, ears per plant, ear weight, and nitrogen content of the grain of five double cross hybrids. Total nitrogen and nitrate nitrogen determinations were made on whole plant samples, lower culms, upper culms, leaf sheaths, and leaf blades of six single cross hybrids at 20- and 40-inch row spacings at both irrigated and nonirrigated locations in 1964. Forage yields were taken; however, no grain yields were obtained due to hail and drought.

In 1963, no differences were noted among row spacings. Significant differences were found among hybrids for grain yield, ear weight, and grain nitrogen. Highest yields were associated with heavy ears and resulted in reduced nitrogen content of the grain.

In 1964, row spacing did not significantly affect forage yield. Single-cross hybrids containing WF9 produced the highest forage yields with the lowest concentration of total nitrogen and nitrate nitrogen. The inbred line 38-11 was associated with low forage yields and high nitrogen concentrations, particularly of nitrate. Accumulations of organic nitrogen per acre across the hybrids were nearly equal; thus hybrids containing 38-11 required larger amounts of organic nitrogen for comparable yields.

When nitrate nitrogen was compared to total nitrogen it was found above a certain level (not within the limits of the experiment) all nitrogen entering the lower culms remained as nitrate. When nitrate nitrogen from the whole plants was plotted against total nitrogen it was

observed that 84 percent of the nitrate nitrogen remained in the nitrate form for the irrigated location. This compared to 47 percent for the nonirrigated location. This striking difference was attributed to the formation of ears and grain of the irrigated corn. Assimilated nitrogen was translocated from the plant to the grain, leaving the vegetative portions of the plant with more nitrate nitrogen (relative basis) than expected.

The upper culms, leaf sheaths, and leaf blades did not accumulate nitrate nitrogen. Work by Hanway (1962) would indicate much higher levels of total nitrogen before nitrates accumulate.